SOLAR PARTICLE EVENT EXPOSURES AND LOCAL TISSUE ENVIRONMENTS IN FREE SPACE AND ON MARTIAN SURFACE

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INTRODUCTION

Solar particle events (SPEs) are a concern to space missions outside Earth's geomagnetic field. The September 29, 1989 SPE is the largest ground-level event since February 23, 1956. It is an iron-rich event for which the spectra are well measured. Because ten times this event matches the ground level data of the February 1956 SPE, it is suggested that an event with ten-times the scaled spectra of the September 29, 1989 SPE be used as a worst case SPE for spacecraft design. For the worst case SPE, the input spectra were reconstructed using Nymmik's (1995) model for protons, the O and Fe ion spectra of Tylka *et al*. (1997) to evaluate the iron enhancement ratio, and the Solar Energetic Particle Baseline (SEPB) composition of McGuire *et al*. (1986) for the heavy ions. The necessary transport properties of the shielding materials and the astronaut's body tissues are evaluated using the HZETRN code. Three shield configurations (assumed to be aluminum) are considered: space suit taken as 0.3 g/cm^2, helmet/pressure vessel as 1 g/cm^2, and equipment room of 5 g/cm^2. A shelter is taken as 10 g/cm^2 on the Martian surface. The effect of shielding due to the Martian atmosphere is included. The astronaut geometry is taken from the computerized anatomical man (CAM) model.

FREE SPACE EXPOSURE

In free space, the hydrogen ions contribute to skin dose equivalent in a space suit over a wide energy range from 60 keV/amu to 45 MeV/amu as seen in Figure 1(a). Helium ions mainly contribute over the 0.3 to 10 MeV/amu range resulting from fragmentation of the aluminum shield nuclei. The Li to B ion group show significant contributions over the range 5 to 30 MeV/amu with heavier ions giving lesser contributions at higher energies (7 to 100 MeV/amu). The higher charge of the ion requires more energy to penetrate to the more protected sensitive tissues. The low-energy primary helium ions attenuate rapidly in shield materials. The helium ions from evaporation events in tissue nuclei dominate at larger shielded depths as seen in Figure 1(b). Note that the evaporation events in tissues cover a narrower energy range than those events in the aluminum shield. Heavier ions attenuate even more rapidly and contribute little to deep organ exposures. Protons and low energy helium ions are the main contributors in well-shielded areas as for the BFO in a space suit. The hydrogen and helium ions show similar broad energy contributions in the skin exposures with the helium result showing significant attenuation compared to the space suit exposures. The heavier ions are likewise reduced relative to the hydrogen contributions. Results for other body organs in various shield configurations are shown in Table 1. The total dose equivalent is significantly reduced in going from the space suit, to the pressure vessel, and to the equipment room. But, even a heavily shielded equipment room of a space vehicle does not provide sufficient shielding to satisfy the exposure limitation requirements of 25, 100, and 150 cSv for the BFO, ocular lens, and skin, respectively. This SPE may have dire consequences without a well-shielded region. A more heavily shielded region of a space vehicle is necessary to meet currently accepted limits.

MARTIAN SURFACE EXPOSURE

On the Martian surface, the contribution of heavier ions than helium is attenuated rapidly because of the shielding effect of Martian atmosphere and additional protection from the Martian surface. The evaporated helium ions and high-energy protons are dominant at the local sensitive tissues inside typical space suit and a lightly-shielded helmet shown in Figure 2. In these figures, the narrowing of the helium ion energy range is apparent. Dose equivalents of the organs in various shields are summarized in Table 2 for the worst case of SPE on Martian surface. For this SPE, shielding for the early response at skin and ocular lens is sufficient except at the BFO on the Martian surface. The 30-day exposure limits at the BFO are exceeded inside various shields except inside the shelter. According to the present estimates, the protection of the sensitive tissue of the BFO would be reached on Martian surface operations when adequate provision is made to seek the shelter in the case of this SPE.

CONCLUDING REMARKS

If the scaled September 29, 1989 event is a reasonable representation of the February 23, 1956 spectrum, then the design of adequate shielding for the Mars transfer will be an engineering challenge. In addition, careful attention also needs to be given to the evaluation of early radiation effects in micro-gravity and in the Martian gravity.

REFERENCES

McGuire, R. E., T. T. von Rosenvinge, and F. B. McDonald, The Composition of Solar Energetic Particles, *Astrophys. J.*, **301**, pp. 938-961 (1986).

National Council on Radiation Protection and Measurements, in *Guidance on Radiation Received in Space Activities*, NCRP Report No. 98 (1989).

Nymmik, R. A., Behavioural Features of Energy Spectra of Particles Fluences and Peak Fluxes in Solar Cosmic Rays, *Proc 24th Intern. Cosmic Ray Conf*., 4, pp. 62-64 (1995).

Tylka, A. J., W. F. Dietrich, and P. R. Boberg, High-Energy Solar Heavy Ions from IMP-8, *Proc. 25th Intern. Cosmic Ray Conf.*, 1, 101 (1997).

Table 1. Dose equivalent from the worst case SPE in free space (in *cSv*)

	Skin			Ocular lens			BFO		
Charge	Space suit	Pressure vessel	Equipment room	Space suit	Pressure vessel	Equipment room	Space suit	Pressure vessel	Equipmen t room
Z=1	17,380	5,540	577	6,680	3,180	501	378	314	168
Z=2	11,490	820	66	1,330	330	49	40	35	24
3≤ Z ≤10	530	50	2	90	20	2	1	1	< 1
11≤ Z ≤20	90	20	1	20	10	1	1	1	< 1
21≤ Z ≤28	20	10	2	10	10	1	1	1	< 1
Total	29,510	6,440	648	8,130	3,550	554	421	352	193
NCRP 30-day limit	150			100			25		

Table 2. Dose equivalent from the worst case SPE on Martian surface (in *cSv)*

	Skin	Ocular lens	BFO
Space suit	45	44	32
Helmet/Pressure vessel	44	42	31
Equipment room	38	37	28
Shelter	33	32	25

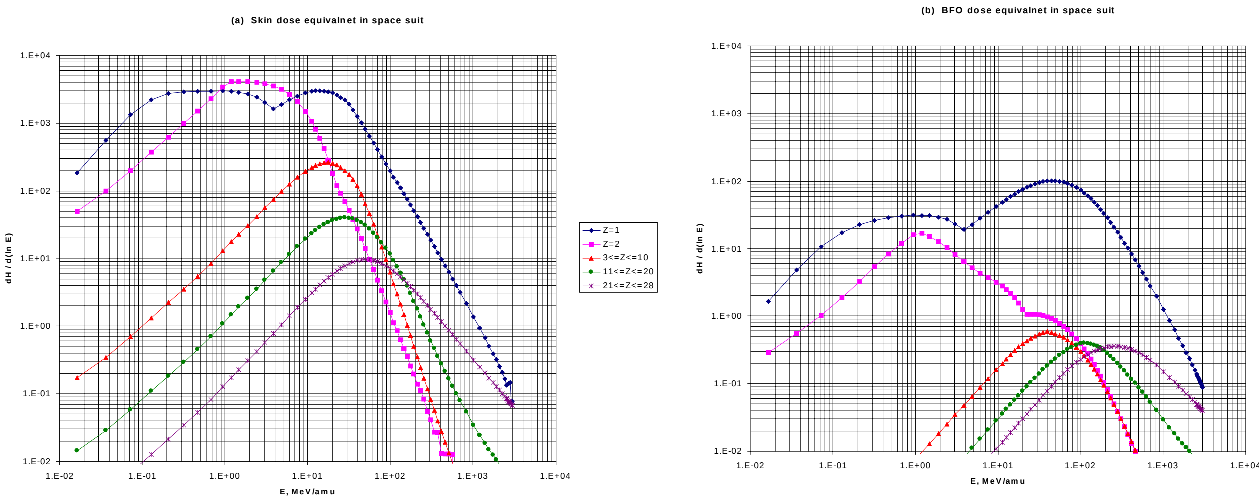

Figure 1. Dose equivalent from the worst case SPE exposure in free space.

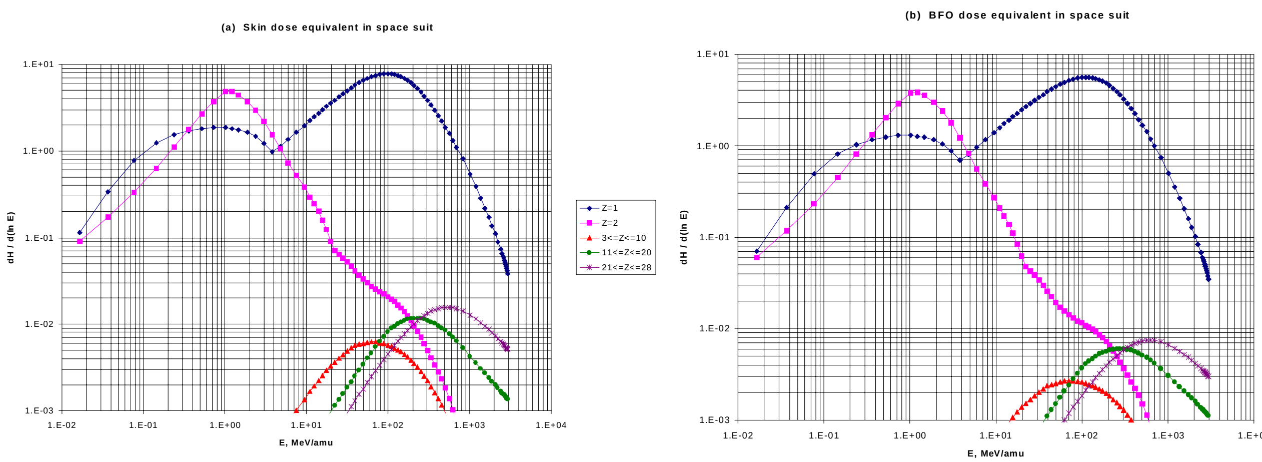

Figure 2. Dose equivalent from the worst case SPE exposure on Martian surface.